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FARMERS' BULLETIN 394.

THE USE OF WINDMILLS IN IRRIGATION IN THE SEMIARID WEST.

BY

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., January 31, 1910.

Sir: I have the honor to submit herewith material for a bulletin dealing with the practical phases of the utilization of wind power in securing water for irrigation, prepared under the direction of Samuel Fortier, chief of irrigation investigations, by P. E. Fuller, irrigation engineer. The Great Plains are being taken up by settlers who must, for the most part, farm them without irrigation, on account of the limited water supply. The rainfall in that section is always light, making this settlement to a certain extent hazardous. Large wind movement, however, provides a cheap source of power for lifting underground water for the irrigation of small areas, in connection with the farming of larger areas without irrigation. This material has been prepared for the purpose of assisting settlers in developing and utilizing power from the wind for irrigation. It is therefore recommended that it be published as a Farmers' Bulletin.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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INTRODUCTION.

Within the semiarid region there are millions of acres of rich, fertile land, now barren, some of which will be reclaimed through irrigation, but most of which can not be irrigated on account of the limited water supply, and must be farmed, if at all, without irrigation. The growing of drought-resistant crops, and improved methods of culture have done and will do much to make the farming of these lands less hazardous, but at best success is greatly threatened by droughts, which occur with greater or less frequency. This land is now attracting eastern farmers who are prone to risk failure in view of the possibilities in years of favorable precipitation. There have been many deplorable failures during the recent years which could have been averted had the unfortunate settlers fortified themselves against periods of drought by irrigating small parts of their land holdings. It is realized that to accomplish this requires an outlay of capital and if this outlay is great it precludes the possibility of such procedure.

With a view to helping these settlers, this Office has investigated the use of windmills as a means of pumping water for the irrigation of small areas in connection with the farming of more extensive areas without irrigation. It is the purpose of this bulletin to set forth in a simple, comprehensive way the possibilities of irrigation, using windmills only as a means of power.

SOURCES OF WATER SUPPLY.

Before choosing a location for a homestead the settler should investigate the underground water supply. This can be done with some degree of assurance by inquiring of those having wells in the vicinity. The points desirable to know are: (1) Depth to water level; (2) nature of material encountered in driving wells; (3) amount the water lowers in the well during pumping; and (4) kind of well, whether bored or dug. With this information some idea of the amount of water which can be expected in the vicinity can be formed.

In event that no such information is available, it is best to put down a temporary test well upon the highest point of land within the area embraced in the proposed homestead. A bored test well 3 or 4 inches in diameter will suffice to show the nature of the formations underlying the surface, and if the supply of water is good the well may

be kept for permanent use. Certain formations yield good supplies, while others, though yielding permanent supplies, do not yield large quantities, and should be abandoned. Generally a coarse sand with numerous bowlders, if of some depth, will promise a large yield. Coarse sand, gravel, or fine sand alone, will yield satisfactory volumes of water. Sand and bowlders mixed with clay or lime are usually so close as to offer great resistance to the underflow, and possess limited voids or space for water between the particles. By filling a pail or can level full of the dry material encountered in sinking a well, and then pouring water from a similar vessel into that containing the material until it will contain no more water, the proportionate volume of the material that is void or empty space will be found. A very promising formation is one which contains 50 per cent by volume of voids or, in the above test, one which will hold one-half its original volume of water. If the formation be sandstone or a conglomerate, the quantity of water which can be secured will be very limited. The thickness of the water-bearing strata should be ascertained if possible, for upon this also depends the quantity of water obtainable.

QUANTITY OF WATER AVAILABLE.

The quantity of water to be expected from a well can not be stated definitely, though a 10-inch or 12-inch bored well penetrating 15 feet of bowlders and gravel or coarse sand and with properly perforated casing should yield 100 gallons per minute. A 15-inch well penetrating 150 feet of coarse bowlders and sand in which 60 per cent of the mass is voids may yield as high as 1,000 gallons per minute. Dug wells supply a larger volume of water than bored wells of the same depth, though they are impracticable and expensive where the water is far below the surface and where the water-bearing material is to be penetrated to any great depth, because of the necessity of pumping to keep the water down during the sinking and because of the great cost of excavation and curbing.

Where a good water-bearing stratum can be found at a small depth a dug well 6 feet square need not penetrate the stratum more than 10 feet to secure 100 gallons per minute, and where a small pump and gas engine are available for temporary use they may be employed in sinking the well to the desired depth, and by this means the well may be tested during the sinking, the digging continuing only so far as may be necessary to secure the quantity of water desired, which should be not less than 100 gallons per minute for ordinary irrigation windmills. It is desirable to sink the well in the driest time of the season, as the minimum rate of flow will then be secured and the necessity of sinking the well deeper when dry seasons occur will be averted.

WELL CASING.

If the well is to be bored and cased, it should be not less than 10 inches in diameter. For coarse bowlders, gravel, and coarse sand, use light drive pipe known as screwed casing, having butt joints.[a] The lower end should have a tempered-steel drive shoe. This casing should be perforated by drive-slitting, by punching, or by a wheel perforator after the casing is in place. Another casing equally well suited is a standard double stove-pipe casing which is a sheet-steel pipe riveted together usually in lengths 2 feet long. These lengths are slipped together with "staggered" joints as the work of sinking proceeds. At the lower or inserting end four or five of these joints are riveted together, double or treble thicknesses being used, and a drive shoe of tempered steel is riveted on. This casing should not be driven but inserted by the use of hydraulic jacks. Perforation of such casing is done after the well is completed, and can be done best with hydraulic jacks. This casing is recommended for wells 10 to 24 inches in diameter.

If the water-bearing material is coarse sand and gravel, either of the above casings may be used, though the slits must be made narrower than for coarse material. The light drive pipe above mentioned may be perforated before being inserted by drilling one-eighth inch or three-sixteenth-inch holes profusely through the lower lengths where the water-bearing stratum is encountered, though the great number of holes required makes the method laborious and objectionable and the holes may become clogged by the coarse pieces of gravel, thereby closing the perforations.

If the material encountered is fine sand or quicksand, there is but one practicable method of securing the water through perforations without permitting the fine sand to flow in and fill the well, and this is by the use of a strainer having extremely fine slits, but beveled on the inside so that any particles which enter the slits will pass on through. One type of strainer consists of a brass, copper, or iron seamless tube, milled or slotted from the inside. In another type the pipe of which the strainer is made is drilled with half-inch holes and then wound with wire having a trapezoidal cross section, the width of the spaces left in winding the wire depending upon the fineness of the water-bearing material. These spaces widen from the outside in, so that they can not clog. Sometimes the wire is wound directly on the pipe and sometimes it is wound over strips laid along the pipe, in order to give the water free circulation along the pipe.

The fine material which can pass such a strainer will be pumped from the well. It is claimed for these strainers that in allowing the

[a] Butt joints are so threaded as to permit the ends of the pipe to pass halfway through the coupling and butt against each other at the ends.

fine material to pass they clean this material from the water-bearing gravel, thus improving the flow of water into the well, but leaving the coarser material to itself act as a strainer. In some instances where such strainers have been used 10 to 12 cubic yards of fine sand have been pumped from a single well in developing the natural strainer area in the surrounding stratum, and in one instance 1,200 gallons of water per minute is being pumped from a 9⅝-inch well put down in a fine sand formation, and depressing the natural water plane but 13 feet from normal. Such a strainer may be used with any of the types of casing mentioned except stove-pipe casing. After the well is completed the strainer is inserted and lowered to the bottom of the hole. The casing is then raised high enough to expose the entire length of the strainer to the water-bearing material. A tight joint between the casing and the strainer is made by having a lead ring on the upper end of the strainer, into which a conical weight is dropped, forcing the lead out against the inside of the casing (fig. 1). The bottom of the strainer is of course closed so that no sand can pass into the well. The top of the casing then projecting above the ground may be cut off. Attempts to use galvanized casing as light as 26-gauge iron, with hatchet-cut slits, as a substitute for a strainer in such fine material have nearly always met with failure, and while such casing has been inserted successfully in some instances its cheapness is the only feature that commends its use.

FIG. 1.—Method of making tight joint between casing and strainer.

Where the material encountered in boring a well is sand only, with no bowlders, it is feasible to use a light casing, say, 18 or 20-gauge iron, having knife slits punched in manufacturing; but even under such conditions it should be inserted inside a heavier casing after the well is completed, and the heavy casing should then be drawn, leaving the light permanent casing in place, thereby avoiding the strain due to driving and forcing the lighter casing.

Many wells fail to supply the proper amount of water because of insufficient perforation in the casings, and while no set rule can be given it is better to have an excess than not enough. The water in its passage through the water-bearing material meets with resistance, and the velocity is therefore slow. If only a limited area of perforations is provided, only small streams of water will enter the well and the pump will draw the water down until it takes air through part of a stroke, while the water level outside the casing will be but slightly lowered.

The writer has adopted the following general rules: Provide a total area of perforation in the casing exposed to inflow of ten times the sectional area of the casing if the bottom end remains open and eleven times the sectional area if the bottom of the casing be closed by being inserted into an impervious stratum. If fine quicksand be encountered, a greater area should be provided, say, fifteen or sixteen times the sectional area of the pipe. Care must be taken not to weaken the casing in perforating it when in place. The slits are usually 8 to 12 inches long, three or four slits being made in each ring or circle. A space of 4 inches is then skipped and a second ring or circle of slits is made, staggered from the preceding set. These perforations are of course made only in the water-bearing stratum.

SINKING WELLS.

While it is not the intention to discuss in this bulletin the sinking of wells, since this work is usually done by contract rather than by settlers, it may be well to make a few suggestions in connection with well drilling, and much time will be saved the farmer if he insists upon their enforcement.

BORED WELLS.

The sand bucket should be not less than 2 inches smaller in outside diameter than the inside diameter of the casing, and should have a steel shoe with a flap valve of as great an area as the bucket will allow. Often a well driller's outfit will contain a dilapidated bucket possibly 3 or 4 inches in diameter and having a round, worn-out, soft iron shoe, with a small valve in the bottom which is hardly one-half the size the bucket will allow, and, if permitted, he may attempt to sink a well 10 inches in diameter with such a bucket. Similarly, the bit may be too small for the well contemplated, and the result is that the casing is battered or punched by its side thrust. Another common cause for failure and delay is the attempt to drill ahead of the casing. Occasionally an attempt is made to drill the entire hole and insert the casing afterwards. While this may be possible above the water level, if the formation is hard and self-sustaining, or in oil wells, where much of the drilling is through shale or sandstone, the casing should be at the very bottom of the hole during the entire process of drilling when the formation is sand, gravel, or bowlders.

The writer has seen material removed from a well which would represent ten such holes; in one instance a cave was excavated which required 20 yards of concrete to fill the void. This was caused by the casing being hung while the drilling continued, in the hope that the casing would finally drop into place.

The use of hydraulic jacks is to be commended in all instances, as it permits continued drilling while a slight pressure is constantly exerted upon the casing thereby tending to keep it on a level with the work. If the driller's outfit be examined and proper tools be insisted upon before a contract is let for the well, much annoying delay to the farmer and expense to the driller may be avoided. Where wells are to be bored in sand, a method of jetting may be employed in sinking the well, which consists of forcing water under pressure through a small pipe to a jet at the bottom of the well which cuts out the material and causes it to rise in the casing as the work of sinking proceeds. This method is not, however, adaptable to the majority of wells, owing to the presence of bowlders and sometimes of slowly soluble material.

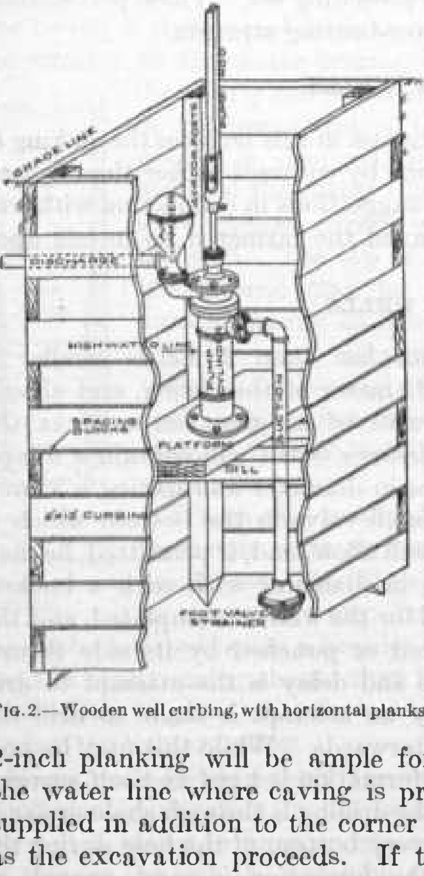

FIG. 2.—Wooden well curbing, with horizontal planks.

DUG WELLS.

Dug wells are too common to require a lengthy explanation. The curbing may be of timber, stone, or brick. Concrete has been used, though it shuts off the side or face area exposed to inflow. Stone or brick laid loosely provide the best curbing, though timber laid against corner posts and placed so as to leave narrow slits at the joints is a cheap and simple substitute for stone, but its life above the water line is short. If timber is used and the earth above the water line will stand without caving, 4 by 4 corner posts and 2-inch planking will be ample for depths up to 12 feet, but below the water line where caving is probable 4 by 4 side posts should be supplied in addition to the corner posts. Such curbing can be driven as the excavation proceeds. If the material throughout the entire depth is loose and tends to cave, a better plan is to frame bents of 6-by-6-inch timber, setting the plank curbing vertically back of the bents and following the excavation down by alternately driving each plank, which is sharpened from the inside, adding bents as the depth increases. The distance between the bents should not exceed 4 feet for depths up to 12 feet, and 2 to 3 feet for lower depths. Figures 2 and 3 illustrate such timber curbing.

WELL POINTS.

The use of well points is to be condemned where irrigation by windmills is considered, for the reason that the area exposed to inflow soon becomes obstructed by sand particles and is therefore entirely too small and the water supplied within the casing may be exhausted during even a small part of a pump stroke, leaving the remainder of the stroke to be supplied with air, or producing a partial vacuum. Further, there is a constant source of doubt as to whether the pump is securing the proper amount of water, or the slip is excessive, or the valves are failing to work. In cases where a small cylinder is pumping limited quantities of water for stock or for domestic use, and the depth to water is great, the use of a well point, if sufficiently large, may be allowable, though it is frequently the source of much trouble and should be avoided even in such cases if possible.

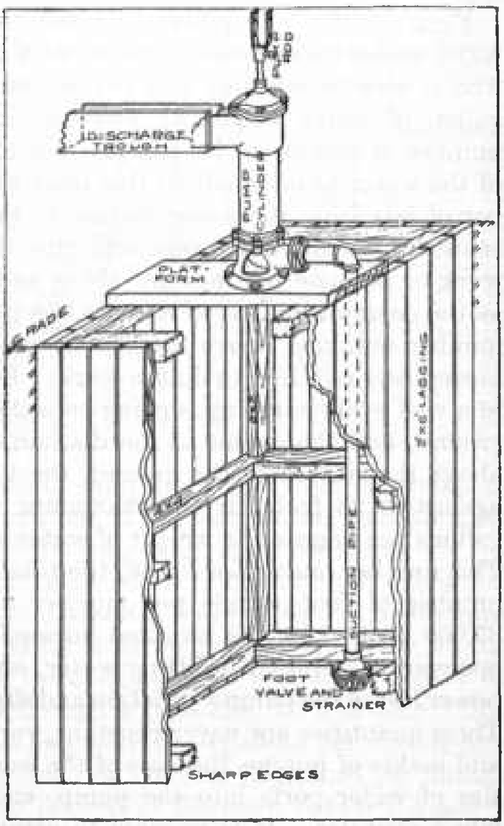

FIG. 3.—Wooden well curbing, with vertical planks.

It should be borne in mind that what has been said regarding bored and cased wells refers to the semiarid region in particular, where, as a rule, the water occurs at a considerable depth below the surface. While the dug well is preferable, it is more particularly suited to shallow depths, and unfortunately favorable conditions for such wells occur only when the land is in proximity to a stream underflow, and such conditions are not characteristic of the semiarid region.

It is evident also from the foregoing that if the bored cased well be used in shallow depths its diameter must be increased to permit the use of a pump of large diameter, so that a much larger volume may be pumped.

After the well is completed it should be tested for at least twelve hours continuously, though preferably longer, to determine the size

of windmill and pump required. The quantity of water constantly flowing can be found by measuring with a bucket, or preferably with a weir.

CAPACITY OF MILLS.

The method of determining the size of mill to use and the principles involved, together with examples, are discussed below.

POWER REQUIRED TO PUMP WATER.

Figuring the horsepower required to pump a given quantity of water under known conditions is not a difficult problem, and anyone who is able to multiply and divide can make the calculation. One gallon of water weighs $8\frac{1}{3}$ pounds. This multiplied by the total number of gallons to be pumped per minute gives the total weight of the water to be handled; this total weight multiplied by the number of feet from the water surface in the well while pumping to the center of the discharge pipe will give the number of foot-pounds of work to be done per minute. Now as one horsepower is considered as the energy required to raise 33,000 pounds 1 foot in 1 minute, the number obtained above divided by 33,000 will give the theoretical horsepower required to do the work. For example, if the water level in a well while pumping is going on is 25 feet below the surface of the ground, and the center of the discharge pipe of the pump is 3 feet above the surface of the ground, the total measured head to pump against is 28 feet. If the maximum volume to be pumped is 60 gallons per minute the weight of water is 60 times $8\frac{1}{3}$, or 500 pounds. This number multiplied by 28, the total lift in feet, gives 14,000, the number of foot-pounds per minute, and this number divided by 33,000 gives 0.42, the required horsepower. This is the theoretical horsepower required in lifting water, and to this must be added the power lost in the pump by friction and slip and in the piping by friction. These quantities are never constant, varying with the different types and makes of pumps, the sizes of the suction and discharge pipes, the size of water ports into the pump, and the head under which the pump operates. It is possible to attain a pump efficiency as high as 70 per cent, but 50 per cent is more nearly the average under field conditions; that is, one-half of the power is lost in overcoming friction or in useless work, and to overcome this we must consider that the net horsepower computed is only one-half of the amount the mill must be capable of delivering to the pump, so that in the case cited above we must have a mill capable of developing 0.84 horsepower.

FRICTION OF FLOWING WATER IN PIPES.

If the water is to be carried some distance from the pump to a reservoir, then the pipe line conveying the water to the reservoir will

offer friction to the flow, and this friction expressed in feet should be added in determining the total head against which the pump must operate. The following table shows the friction head in feet for pipes of various sizes when carrying different quantities of water:

Feet of friction head in clean wrought-iron pipe for each 100 feet of length when discharging various quantities of water.

Gallons per minute.	Friction head in pipe, with diameter of—														Size of pipe to use for economical distribution.
	¾ in.	1 in.	1¼ in.	1½ in.	2 in.	2½ in.	3 in.	4 in.	5 in.	6 in.	7 in.	8 in.	10 in.	12 in.	
	Feet	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Inches.*
5	7.60	1.93	0.71	0.27	0.07										1.5
10	29.95	7.28	2.42	1 08	.28	0.07									2.0
15	66.12	16.08	5.48	2.23	.62	.14									2.0
20	116.12	28.33	9.37	3.82	.97	.30	0.07								2.0
25	179.71	43.77	14.74	6.03	1.53	.48	.23								2.5
30		63.36	21.08	8.64	2.09	.69	.28	0.07							2.5
35		85.24	28.56	11.63	2.90	.96	.32	.11							2.5
40		110.59	37.09	15.02	3.68	1.17	.39	.13							3.0
45			46.54	18.77	4.63	1.42	.62	.16							3.0
50			57.37	23.04	5.62	1.86	.80	.20	0.07						3.0
75			129.25	51.61	12.25	4.14	1.70	.48	.13	0.07					4.0
100				89.85	21.79	7.37	3.01	.70	.27	.11					5.0
125					34.33	11.26	4.58	1.17	.39	.16					5.0
150					48.84	16.12	6.56	1.58	.57	.23		0.05			6.0
175					64.74	21.79	8.87	2.18	.78	.32	0.07	.07			6.0
200					86.40	28.73	11.56	2.80	.97	.39	.18	.11	0.02		6.0
250						45.29	17.87	4.34	1.49	.60	.30	.16	.07	0.02	7.0
300						64.65	25.80	6.12	2.13	.85	.41	.20	.09		8.0

The length of pipe necessary to carry the water from the pump to the reservoir, expressed in hundreds of feet, should be multiplied by the friction head loss for each 100 feet, as given in the table.

It is well to select a size of pipe which will carry the maximum volume of water at a velocity of about 2 feet per second in the pipe line. The sizes recommended for a given volume are given at the right of the table. Suppose, for example, it is desired to deliver 60 gallons of water per minute through a pipe line 100 feet long. The table shows that a 3-inch pipe line delivers 50 gallons per minute at a loss of 0.8 foot head and a 4-inch line delivers 75 gallons per minute with 0.48-foot loss. The size desired is therefore between 3 and 4 inches, and as no intermediate size is made in wrought-iron pipe, the 4-inch pipe is best, and the total head to pump against would be in the example given 25 + 3 + 0.48, or a total of 28.48 feet.

It has been suggested that an open trough having a pitch or slope from the pump to the reservoir is preferable to a pipe line; but while this may be cheaper there is no saving in the head required, for if a trough be used the power required to raise the water high enough to flow to the reservoir through the trough is as great as that required to force it through the pipe. It may, in fact, be a little greater owing to the greater roughness of the trough as compared with the pipe line. Of course where the reservoir is adjacent to the pump a trough will

be a more simple method of conveyance and it makes possible the use of a somewhat different type of pump, described later. The use of riveted pipe in lieu of smooth wrought iron is to be condemned because of the greater roughness and consequent greater loss of head.

TO DETERMINE SIZE OF MILL.

The feasibility of windmill irrigation depends much upon the head or height the water must be lifted from the well, and it is proper that a word of warning be given to discourage the use of windmills for irrigation purposes if the water table or level be over 60 feet from the surface of the ground; for, while the raising of small quantities of water by such power for stock or domestic use is perfectly feasible, the limited power of the ordinary mill is not sufficient to pump the large volumes needed for irrigation against a large head. As there is only a small percentage of time during which the wind attains a velocity favorable to the most economical mill load, the total quantity of water will be small at best, unless, of course, a very large mill is used.

On page 15 is given a table of wind velocities at Cheyenne, Wyo., during the months of April, May, June, July, August, and September for five years, 1904–1908, where six mills of various makes are installed for irrigation purposes. While the average monthly velocity in this section of the Rocky Mountain district is higher than in other localities farther south and east, the relation is not so different as to vary materially the corresponding calculated velocities elsewhere. To calculate the probable performance of a mill in a particular locality it would be well to secure from the nearest Weather Bureau office a report of the wind velocities for that district for several years and set down the various lengths of time that the wind has attained certain velocities. Then get from the manufacturer of windmills his guaranty as to the amount of power the mill will yield at the pump, together with the speed of the wheel in wind velocities ranging from 6 to 30 miles an hour.

It must be borne in mind that wind movement is never constant nor regular, frequently varying from a rate of 10 to 25 miles an hour within a few minutes' time. The methods commonly employed of measuring wind velocity do not take into account this continuous fluctuation because of the fact that the cup anemometer, however light, can not respond instantly to quickly varying impulses because of its inertia, and slowly loses its speed after a sudden impulse followed by a lower velocity. Consequently, only an average rate of wind movement is secured by such methods of measurement. The tabulation of the wind movement at Cheyenne, Wyo., covering the possible irrigation months during five years, 1904–1908, will serve as an example.

Wind velocities at Cheyenne, Wyo.

Year and month.	Hours during which the wind's velocity per hour was—								
	0 to 5 miles.	6 to 10 miles.	11 to 15 miles.	16 to 20 miles.	21 to 25 miles.	26 to 30 miles.	31 to 35 miles.	36 to 40 miles.	40 miles and over.
1904:	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*
April	136	207	187	111	49	19	6	2	3
May	158	281	154	97	36	14	4	...	...
June	200	300	151	47	10	12	...	...	...
July	245	293	139	51	15	1	...	...	...
August	249	298	124	59	14	2	...	...	...
September	284	300	89	39	7	1	...	...	...
1905:									
April	159	255	203	83	20	25	...	...	...
May	169	271	186	86	28	4	...	...	...
June	172	262	159	87	21	12	7	...	...
July	282	302	93	36	23	18	...	...	...
August	271	303	123	43	3	1	...	...	...
September	257	297	104	37	9	10	6	...	...
1906:									
April	125	297	167	67	38	24	2	...	...
May	188	253	165	79	30	21	7	1	...
June	156	220	166	79	52	16	15	10	6
July	310	313	102	13	6	...	...	...	...
August	265	299	134	37	6	3	...	...	...
September	208	308	130	58	11	3	2	...	...
1907:									
April	126	278	167	83	39	15	15	6	1
May	158	310	165	72	41	19	5	...	...
June	176	294	140	70	31	16	2	1	...
July	251	307	152	30	3	1	...	...	...
August	217	281	142	87	16	...	...	1	...
September	239	242	131	83	19	4	2	...	...
1908:									
April	151	244	146	101	38	17	18	13	2
May	143	249	171	95	60	19	5	2	...
June	198	283	147	50	34	6	2	...	...
July	260	346	107	24	7	.4	...	...	...
August	286	309	107	35	3	4	...	...	...
September	260	306	115	30	9	...	...	...	...
Total	6,299	8,508	4,266	1,869	678	287.4	98	36	12
Mean [a]	209.9	283.6	142.2	62.3	22.6	9.58	3.3	1.2	[b].4

[a] Per month. [b] Mean at 43 miles.

In five years the wind during the months of April, May, June, July, August, and September had a velocity of less than 5 miles an hour for a total of 6,299 hours, or an average of 209.9 hours per month; it attained a velocity of 6 to 10 miles per hour during 8,508 hours, or an average of 283.6 hours per month. It attained a velocity of 26 to 30 miles during only 287.4 hours, or an average of only 9.58 hours per month.

Many mill manufacturers stipulate that their mills will perform certain work in an average velocity of 16 miles per hour during eight hours per day, but this is misleading and may result in an overestimate of the results expected, for while the average velocity may be 16 miles per hour the velocity for a part of the time may be too low to run the mill and for a part of the time too high to run it economically, thus producing much less power than a steady 16-mile wind. The average hourly velocity should not enter into the choice of a mill, but the time during which the wind reaches certain rates per hour should be the basis upon which a mill and pump should be chosen.

To illustrate this, the result of a test with a 14-foot power type of mill may be cited. In different wind velocities the mill was operated with varying loads, and the power developed and the number of revolutions of the wheel per minute with each load were recorded. These data were platted and diagrams were constructed showing the power developed (fig. 4) and the number of revolutions of the wheel (fig. 5) under different conditions. The following table shows for different wind velocities the loads under which the mill developed the greatest

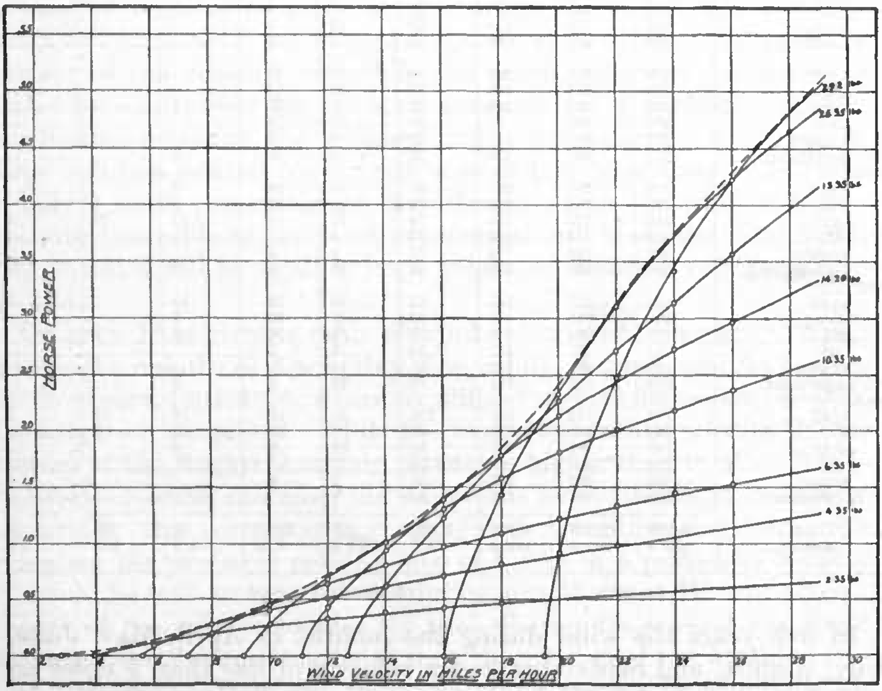

FIG. 4.—Diagram showing power developed by 14-foot mill with different loads in different velocities.

power and the speed of the wind wheel when the maximum power was being developed:

Loading and speed of 14-foot power mill when developing its maximum power.

Wind velocity—miles per hour.	Horse-power.	Speed of wheel—revolutions per minute.	Load in pounds per stroke.
0-5	0.01	2.0	....
6-10	.27	20.0	4.35
11-15	.85	29.5	10.35
16-20	1.80	38.0	14.20
21-25	3.45	45.0	26.35
26-30	4.82	51.0	29.20
31-35	5.60	55.0	31.00

From this table and the table showing wind velocities at Cheyenne it is possible to compute the work which could be secured from this

mill. If it were possible to vary the load so as to utilize its maximum power, this mill would produce power during a month as shown in the following table:

Total power which could be developed by 14-foot mill, tested at Cheyenne, Wyo., if the load were varied to secure maximum power.

Wind velocity—miles per hour.	Horsepower produced.	Hours per month.	Total horsepower hours.
0-5	0.01	209.9	2.10
6-10	.27	283.6	76.57
11-15	.85	142.2	120.87
16-20	1.80	62.3	112.14
21-25	3.45	22.6	77.97
26-30	4.82	9.6	46.27
31-35	5.60	3.3	18.48
Total			454.40

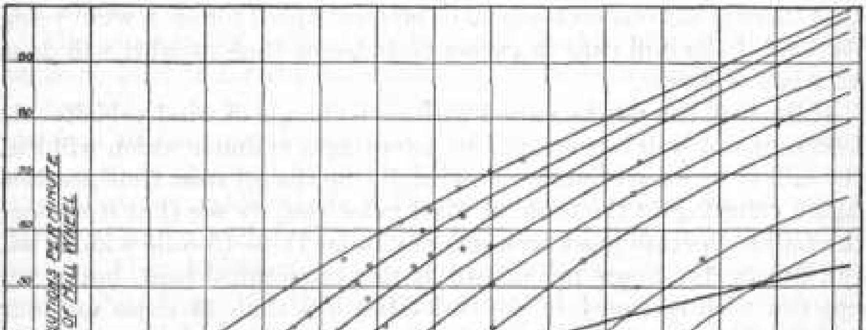

FIG. 5.—Diagram showing speed of wind wheel of 14-foot mill in different wind velocities with different loads.

Theoretically 1 horsepower will lift 3,961.6 gallons 1 foot in one minute, or 237,690 gallons per hour, and this number divided by the number of feet the water is lifted will give the number of gallons lifted per horsepower hour. With an efficiency of 50 per cent, which is ordinarily obtained, and a lift of 28 feet, this would be 4,244.5 gallons pumped per horsepower hour. As shown by the table, the total power produced per month was 454.40 horsepower hours, and consequently the total quantity of water which could be pumped under the conditions assumed would be 1,928,701 gallons, or 5.9 acre-feet,

or 35.4 acre-feet for the six months of the irrigation season—enough water to supply 17.7 acres with a depth of 2 feet.

This, then, is the theoretical performance of this mill if it were possible to adjust the load so as to maintain the mill at its most efficient speed and if the pump efficiency were constant at 50 per cent. The former condition is not attained because the load—that is, the amount of water discharged per stroke—is constant, and to increase the work done by increasing the number of strokes in a given time would, with a fixed gear ratio, necessarily change the speed of the wheel from its most efficient rate; and, further, there is a limit to the practical speed at which a piston pump of that type can be run, which is about 40 strokes per minute. It might be supposed, naturally, that if the load is too small for the mill the small amount of water pumped per stroke would be compensated for by the mill making a greater number of strokes. While this is true to some extent, it should be remembered that there is but one economical or efficient speed for each wind velocity, and if the mill runs in excess of or below that speed it will do so at a loss of power.

If the load can not be varied with each change of wind velocity, the best economy will be obtained by adopting a cylinder which will load the mill at its most economical point during the greatest time possible. Again referring to the table of wind velocities, we see that if we load the mill to operate most economically in an 11-to-15-mile wind it will run during 142 hours per month at this economical load, but it will not run with economy in any velocities less than 11 miles an hour, and it will run less efficiently also during 62.3 hours in the 16-to-20-mile wind and during 22.6 hours in the 21-to-25-mile wind. But this underloading will tend to allow it to run so fast in higher velocities as to exceed the safe pump speed, and will therefore necessitate adjusting the mill so that it will "cut out" at a wind velocity exceeding 25 miles, thereby losing 64.65 horsepower hours of useful work per month. If the load be adjusted for the 16-to-20-mile wind, we can take advantage of operation at higher velocities, but this will entail a loss of 142.2 hours per month in the lower velocity. Hence it will be more advantageous to adapt the load to the 11-to-15-mile velocity.

Now, referring to the horsepower of this mill, it will be seen that it develops 0.85 horsepower in a velocity of 11 to 15 miles, running at a speed of 29.5 revolutions per minute. To pump 60 gallons of water per minute to a height of 28 feet, with a pump efficiency of 50 per cent, requires 0.84 horsepower, or 27,720 foot-pounds per minute. At 29.5 revolutions per minute the work done equals 940 foot-pounds per revolution of the mill wheel if it is of the direct-stroke type, and 2,820 foot-pounds per stroke if the mill is back-geared 3 to 1, because it will necessitate three revolutions of the mill wheel in this case to

make one stroke of the pump, and the pump will be making only 9.8 strokes per minute instead of 29.5, as in the case of the direct stroke. As one-half of the load is considered as friction, the net water load with the geared mill will be but 1,410 foot-pounds. The total head that the pump operates against is 28.48 feet, and the number of foot-pounds of load divided by the number of feet head gives the number of pounds load instead of foot-pounds, as before. This, in the example, would be 49.5 pounds, and the cylinder should be of such size as will in one stroke discharge 49.5 pounds of water. Since 1 cubic inch of water weighs nearly 0.037 pound, the cylinder capacity would be 1,338 cubic inches, and this divided by the length of stroke in inches gives the area of the cross section of the cylinder. Most mills have provision for varying the length of stroke, but it seldom exceeds 14 inches. With this stroke the area of cross section of the cylinder is 95.6 square inches, requiring a diameter of about 11 inches.

The quantity of water that this mill would pump if it were possible to load it for the maximum effect in each wind velocity was computed on page 18, but it has been shown also that without some method of load regulation this is impossible, and that the nearest approach to this will be to load the mill so as to take advantage of the most favorable winds. The quantity of water which will be pumped under such loading with a cylinder having a 14-inch stroke and an 11-inch diameter will now be computed. On the horsepower curve No. 2 (p. 16) the curve designated 10.35 pounds gives the maximum 0.85 horsepower in the wind velocity of 11 to 15 miles per hour; and speed curve No. 1 (p. 17) shows that it requires a 9-mile wind to start the mill, so that in all velocities less than 9 miles per hour the mill will stand idle. The results will be as follows: In an 11-to-15-mile wind it will run at 29.5 revolutions per minute during an average of 142.2 hours per month; in a 16-to-20-mile wind it will run at 50.4 revolutions during 62.3 hours per month; with a wind velocity of 21 to 25 miles per hour it will run at a speed of 66 revolutions per minute during 22.6 hours per month; with 26 to 30 miles per hour it will run at 79 revolutions per minute during 9.58 hours per month; and with 31 to 35 miles per hour it will run at 86 revolutions during 6.5 hours per month. The mill would therefore make 608,640 revolutions during one month, or 3,651,840 revolutions during the six irrigation months. The mill being back geared 3 to 1, the total number of pump strokes will be one-third the revolutions, or 1,217,280 strokes, and as each stroke will discharge nearly 0.79 cubic foot of water, the total quantity of water discharged during the season would be 1,217,280 times 0.79, or 961,651 cubic feet, equal to 22.08 acre-feet of water, or sufficient water to apply 2 acre-feet to 11.04 acres of land.

If the pump is double-acting and discharges water on both the up and down strokes the cylinder should have one-half the area found for the single-acting type, or, in the example, nearly 8 inches in diameter in place of 11 inches, but the result will be practically the same. Should the total head pumped against be one-half that assumed in the example, then the power required to pump the same quantity of water would be less than one-half, or the quantity which could be pumped with the same power would be doubled.

Comparing the quantity which can actually be pumped with this mill loaded most favorably with the quantity it could pump if the load could be regulated, shows a loss of 14.92 acre-feet of water, or nearly two-fifths of the available power. It will appear to the reader no doubt that to load a mill properly requires a more thorough understanding of the problem than is within reach of the farmer; but if manufacturers of mills would provide ratings secured from careful tests which would show the speeds of their mills in different wind velocities and under different loads the problem would not be a difficult one and would involve merely a study of the wind movement for a particular locality to determine which wind velocities were the most prevalent and the most economical load for these velocities.

There is another feature in the choice of a windmill which is confusing to many—that of the difference between the direct-stroke and the geared type of mill. At Cheyenne a 16-foot direct-stroke mill and a 14-foot mill back-geared $3\frac{1}{3}$ to 1 were tested under the same heads, the direct-stroke mill being loaded 413 foot-pounds per stroke and the geared mill 591 foot-pounds per stroke. The total work done is not materially different for these two mills. The direct-stroke mill requires a heavier wind to start, rapidly increases to its maximum, and rapidly descends from the maximum, while the geared mill starts easily, ascends to its maximum more slowly, and continues over a greater time. The conclusion is that the direct-stroke type is possibly a little better where the wind velocity is high for a considerable length of time, while the back-geared type is particularly well suited to high heads and average low-wind velocities. There is an advantage in the mechanical construction, however, in favor of the direct-stroke type of mill, as there is less machinery and consequently less wear than with the geared type.

The relative power of two mills of different diameters is about as the squares of the diameters of the wheels. For instance, if a 14-foot mill develops a maximum of 0.27 horsepower in an 8-mile wind, an 8-foot mill of the same type and relative area will develop $(\frac{8}{14})^2 \times 0.27 = 0.0881$ horsepower.

Much has been said concerning the choice between a large and a small mill wheel. Some mill makers recommend the use of a small mill in preference to a large one on the ground that, if a large mill

is used, the water supply may become exhausted and the mill have to be shut down, while a small mill could be continued in operation at all times without exhausting the supply. Such an argument signifies a fault in the water supply rather than in the mill. No doubt, in view of the fact that the pressure upon a wind wheel increases as the square of its diameter, to resist the strain due to increased diameter, the strength of the mill must be greater and the tower also must be capable of safely withstanding the increased strain. Obviously, to secure greater strength of mill the weight must be increased and the friction loss must be similarly increased; but the increase of friction as compared with mill output will not be so great as it will be in case two small mills are put up with a combined power equal to that of the large one; and certainly the initial cost of one large mill will not be so great as that of two smaller ones. It is evident, therefore, that within reasonable limits the larger mill will be more economical in all ways and is the better size to adopt, providing of course that the water supply is great enough to supply the pump under average conditions of wind. Probably, however, under average conditions, a 16-foot mill will require a cash outlay greater than can be borne at the outset, and it may be better economy to limit the mill to 14 feet and, when a greater supply of water is required and circumstances permit, to install additional mills.

MECHANICAL FEATURES AND TESTS.

Before purchasing a mill it will be advisable to communicate with windmill manufacturers with a view to securing the best and cheapest mill suitable to the requirements. The following questions should always be given particular attention:

(1) Is the mill arranged to oil freely and amply?

(2) Are all parts subjected to wear arranged for easy adjustment?

(3) Are the gears (if geared) and parts heavy and well built?

(4) Has the firm which appears to have the best mill a good reputation for excellency of product?

A guarantee should be asked that the horsepower required will be delivered and maintained in given wind velocities. If it seems desirable to test the mill to ascertain its fulfillment of the guarantee, it can be done by computing the horsepower delivered by the pump, in the manner explained, in the different velocities covered by the guarantee. The wind velocity can be approximated closely by allowing a feather to be blown from the tower at the height of the center of the windmill. The distance, in feet, that the feather travels in a given number of seconds divided by this number will give the rate of travel in feet per second, and this rate per second multiplied by 0.68 will give the rate of the wind in miles per hour.

The power type of windmill—that is, one which transmits its power to a revolving shaft rather than directly to the pump rod—is a very desirable type to use for the reason that a heavy fly wheel may be attached so that the energy may be stored and applied to the pump during the working stroke, and the rotary motion makes the power available for running machinery of any kind. This type, too, permits the use of a double-acting pump, or a pump which delivers water on the downstroke as well as on the upstroke. This is not always practicable with the stroke mill, because of the flexibility of the rod and a tendency to buckle on the downstroke if much power is applied. The power type is usually geared forward in a ratio of four or five to one—that is, for each revolution of the wind wheel the horizontal shaft makes four or five revolutions.

Devices have been applied to equalize the work of the stroke type so that the mill will not be called upon to perform the entire work on the upstroke alone. While such a device tends to distribute the work throughout the greater part of the complete revolution of the crank shaft it does not increase the power of the mill, as is frequently claimed, for the reason that when the mill is loaded to its maximum the wheel acts in a measure as a fly wheel, tending to impart its stored energy at a time when the upstroke is being made; and if the load be greater at this period by virtue of springs so arranged as to store sufficient energy to operate a downstroke of a double-acting pump, the wheel must necessarily be slowed down in performing this additional work. Of course, if the mill be loaded inadequately in a given wind velocity, then the addition of such a device will utilize the available increase in wind energy which would be lost otherwise; but if the mill be properly loaded for its maximum effect, such a device is of no value.

LOAD REGULATORS.

On the preceding pages it was shown that for each variation in wind velocity the load of the mill should be varied if the total power developed is to be utilized. Several devices have been invented for accomplishing this. Some are operated by hand, but this fact alone makes them impracticable. The most successful of the automatic regulators is one which lengthens the stroke of the pump automatically as the wind increases in velocity and shortens the length of the stroke as the wind velocity decreases. If the stroke is shortened, the quantity of water pumped will be less in a given time and the power required will be reduced proportionately and the mill will continue to operate in a low-wind velocity, while if the length of the stroke be increased with the increase of wind velocity the quantity of water pumped will be increased proportionately without the accompanying thrust and strain upon the mill.

A careful record was kept of the mill upon which the stroke regulator was installed. A mean average of the day and night wind velocities was obtained by a standard recording anemometer, while the quantity of water pumped was measured with an integrating impulse water meter of a standard make. The pressure at which the pump discharged was found to average 52 feet total head. Curve *A* on figure 6 shows the average quantity of water pumped per mile of wind at various rates of wind velocities per hour before the stroke regulator was applied. Curve *B*, upon the same diagram, shows the results after the stroke regulator had been applied. The tests in both instances were of several weeks' duration. The wind velocities in all the tests are averages throughout the entire twenty-four hours each day, it being desirable to know the result of constant operation. Had the wind velocity been taken during the daytime only, the quantity of water pumped per mile of wind would have been higher, and the

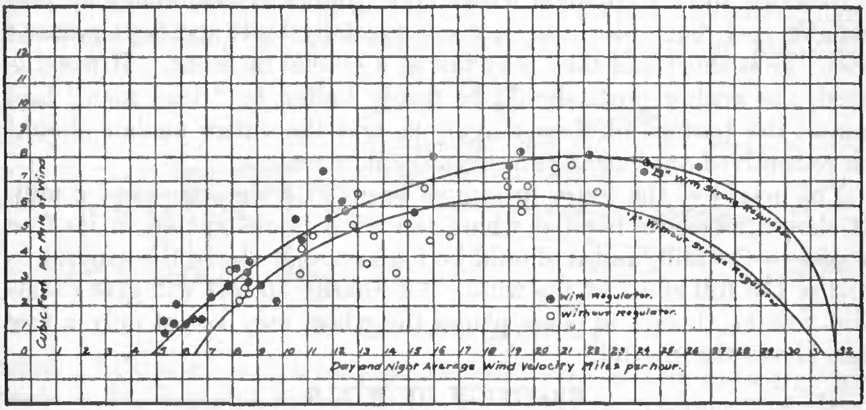

FIG. 6.—Curves showing quantities of water pumped by mill with and without stroke regulator. Head, 52 feet.

time of operation confined to eight hours per day, owing to the fact that the night velocities, while frequently too low to operate the mill at all, were recorded and added to the total wind in a given time. The average gain in water pumped through the application of the stroke regulator was found to be approximately 30 per cent, which gain represents the increase in water pumped in the same total number of miles in a given time. This regulator was loaned to the department for demonstration of its applicability to windmill work. If by certain changes in the mechanical construction its life can be assured, it will no doubt fill a long-felt want in the windmill field.

CHOICE OF TOWER.

The selection of a tower upon which to erect a mill requires no special suggestion, though it is to be regretted that some manufacturers are resorting to the use of pot metal in attempting to cheapen

the cost of towers, and such inherent weakness has resulted in the loss of mills in sudden squalls which possibly would have withstood normally high wind pressures otherwise. It is well to use a tower which is amply strong to withstand the highest wind velocities, even though such strength may not be required ordinarily, as the damage resulting from failure will more than offset the slight additional cost for the added strength. The tripod, or three-legged tower, is lighter and allows trussing in a more correct manner, and even though the parts are proportionately heavier, the total weight is less than that of the four-post tower; but if the tripod tower is cheap or poorly constructed, it is more hazardous than the four-post tower of similar construction.

Careful attention should be given to the anchors and their footings. These should have plates of large area set upon a solid foundation and firmly tamped and bedded in place.

Wooden towers are good where clear timber is available at a reasonable cost, but unless they are substantially built and kept painted their life is short and they may fail at a crucial moment. If wood is used, the anchor posts should be firmly bolted to "dead men" laid across the bottom of the excavation, and the entire anchor should be well tarred or charred to prevent rapid decay.

The height of the tower has much to do with the success of a mill. It should never be located where the wind is obstructed in its free access to the mill, and it should be high enough above the ground to realize the full effect of the wind. Ordinarily 40 feet will give excellent results, though in some places the wheel may be set only a few feet above the ground.

ERECTION OF MILLS.

If more than one mill is used, the location with respect to each other should be given consideration, for if placed in line with the prevailing wind one will obstruct the wind considerably, even if they are placed at such distances apart as 500 feet.

When mills are shipped from the factory they are usually crated and require assembling completely in the field. Instructions always accompany the shipment and with care no trouble will be experienced in the erecting. After the mill is entirely assembled it should be inspected carefully to ascertain whether all the parts are placed correctly. In raising the mill it should be blocked up as high as possible and a 2 by 12 plank should be bolted upon the legs against the ground. Four by four sheer legs should be set astraddle of the tower about one-third up from the base, and over the crotch in these legs a stout cable or rope should be made fast to the mill head, the free end being fastened to a set of tackle blocks. Four-sheave and three-sheave blocks for 1¼-inch rope are best, one end of the blocks being

made fast to the anchor. The free end of the line can be fastened to a doubletree and a team of horses can be used to raise the mill. Three strong guy lines, one in the rear and one on either side, should be made fast to the head so as to steady the mill when raising. Figure 7 shows a mill arranged for raising. It is well to choose a day for raising the mill when no wind is blowing.

PUMPS.

The speed at which pumps of the windmill type give the best results consistent with long life is at a maximum of 40 strokes per minute, but better results will be obtained if the length of stroke is increased beyond that usually adopted by mill manufacturers, leaving the cylinder diameter the same and reducing the number of strokes, but lessening the crank speed by gear reduction so that the quantity of water pumped per stroke is increased. The reason for this is that the column of water would be required to be started less often than otherwise, resulting in less wear and thrust in the pump and mill

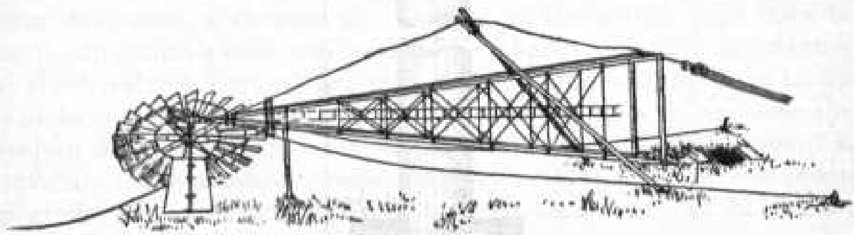

FIG. 7.—Mill and tower arranged for raising.

parts. In this respect a back-geared mill with greater reduction in gears and a consequent longer stroke would be preferable to the direct short-stroke type. Such an arrangement, however, requires that the gears be designed with ample face or tooth area and liberal strength in the parts. When the pump operates against a low head and through only a short and large pipe to the reservoir the objection to short strokes is not so serious.

In choosing a pump for a particular mill the matter of size can be left to the mill manufacturer, but even in such case an understanding of the principles involved is most desirable, as investigation of mills and pumps shows that where no especial attention is given to the proper proportioning of pumps the results are most unsatisfactory.

A few points in the construction of a pump are of great moment to its successful operation and are given herewith.

(1) It should be insisted upon that the pump have a large stuffing box or gland (if it be of the pressure type) where the piston rod leaves the pump. This gland should be packed with a good grade of graphite packing.

(2) The cylinder or its lining should be of brass, seamless, and polished on the inner walls.

(3) The piston should have ample space for the best leather packing and the "follower" should be arranged so as not to become loose.

(4) The piston rod should be of bronze or heavily encased with brass casing, and in either case should be at least 1¼ inches in diameter.

(5) The guides for the crosshead should be of large diameter and be perfectly parallel to the piston rod in all positions.

(6) The ports or water openings through valves should be large and free.

(7) A generous air chamber should be provided at the discharge opening of the pump. Its capacity should be at least three times

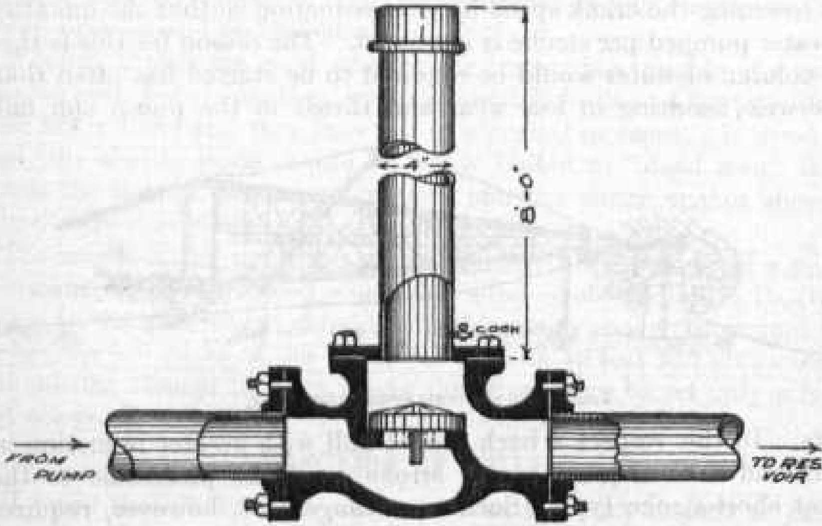

FIG. 8.—Method of combining air chamber and check valve.

the capacity of the cylinder and a greater capacity than this will do no harm. This air chamber must be connected beyond the check valve in the discharge of the pump. In many pumps a small air chamber is provided on the pump, but as a rule it is located at the extreme top of the pump and the piston passes through the stuffing box at the top of the air chamber, and any leak in the gland or stuffing box at the top of the air chamber permits the air to escape and its usefulness is lost. A simple way of providing an extra air chamber is by inserting a horizontal swing check valve in the discharge line just outside of the pump and removing the cap or cover from the check and substituting therefor a simple flange. Into this flange a 3-inch or 4-inch pipe about 8 feet long may be screwed and a cap provided at the other end of the pipe (fig. 8). A small pet cock should be provided at the bottom so as to empty the air chamber of water

occasionally, as the water will in time absorb the air compressed at the top of the cushion. Some manufacturers contend that a standpipe in the discharge pipe line located at the pump and having the free and open end projecting above the highest point on the discharge line gives better results than a closed chamber. This claim is fallacious in view of the fact that the inertia of the column of water in the standpipe is nearly equal to the impact of the horizontal water column in the pipe line to the reservoir, and the water hammer is therefore not lessened as with the air chamber, in which the gradual compression of an elastic body, the air, causes the impact upon the pump rod to be gradual and uniform until the stroke is completed, when the tendency of the air to expand to its original volume keeps the water column moving while the pump is making its return stroke. This is true even with a double-acting pump, in which instance the column would come nearly to rest otherwise, because of the slower rate of velocity of the piston at the end of each stroke.

If the suction lift is great and the pump hammers or pounds from this cause, a vacuum air chamber on the suction pipe close to the pump cylinder inlet will remedy the trouble. In such an instance no check valve is required other than that in the bottom of the pump cylinder. The result of such a vacuum chamber is to continue the column of water in the suction pipe in motion while the pump is traveling its downward stroke. At the suction inlet of the pump or at the end of the suction pipe a large strainer and check or foot valve should be provided which will prevent large gravel entering the pump and will keep it primed at all times.

If the pump is located close to the reservoir, it may discharge through a spout into a trough which carries the water directly into the reservoir. The pump in this case should possess all of the desirable features specified for the pressure type but needs no air chamber or gland in the pump head. In figures 8 and 9, pages 26, 28, pumps of both the pressure and spout types are illustrated in connection with the well curbing and serve to show the method commonly used in installing such pumps.

A pump of the pressure type, which is known as a siphon pump, is illustrated in figure 9. This pump possesses several unique features; the valves can be removed without pulling the entire pump apart, and the brass cylinder lining can be removed easily by taking off the pump bonnet or head. Another feature of this pump is that it always remains primed. However, it possesses the very objectionable feature of an air chamber at the top through which the piston rod passes. An additional air chamber as suggested above was provided for this pump at the Cheyenne station and gave excellent satisfaction.

When the water supply is very meager several pumps can be operated from one mill by an arrangement of bell cranks, though this plan offers many places for lost motion in the flexibility of connecting rods, and should be avoided if possible. Where the supply is very close to the surface and large volumes of water can be pumped owing to the low head, it becomes desirable sometimes to operate two pumps from one mill. In such cases, if the supply is sufficient, a reservoir is not imperative. The connection can be made by a lever not dissimilar to a seesaw arrangement having a pump at either end and the pump rod from the mill connected by a ball-and-socket joint at one end of the lever (see fig. 14, p. 43). There are not, however, many places where the water supply offers such possibilities, and even then a single pump of large diameter, even up to 36 inches, has been used successfully, and is no doubt much more efficient than the two-pump arrangement.

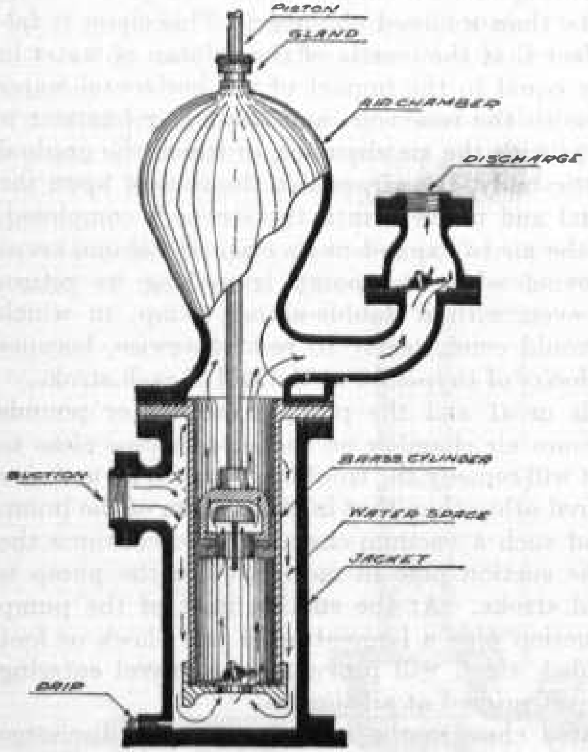

FIG. 9.—Siphon pump.

RESERVOIRS.

Probably the most important adjunct to a windmill plant is the reservoir. Indeed, a means of storing water which is delivered at a small rate of flow should be resorted to in every instance where the flow is less than 600 gallons per minute. The reason for recommending a reservoir for flows up to this amount is that, with small streams used direct from the pumps, the loss in conveyance in ditches is excessive and the loss in the application of the water to the land is large, since a small stream will saturate a spot and a large amount of water will sink into the soil in this one place instead of spreading over a large area and moistening the surface. Further, much more labor is required to irrigate with a small stream than with a large one.

If climatic conditions were favorable and resources not limited, there would be an advantage in having a reservoir which would hold all the water pumped from the time irrigation stops in one season until it begins in the next, for it is during the winter months that the greatest winds occur. Operation during the winter months would require only a large reservoir and the draining of pipes during calm, cold days or, better still, a frost-proof housing for the pump and piping. In many instances a reservoir can be made a source of profit during the winter months by producing ice.

The size and shape of a reservoir are important. A circular reservoir contains about 13 per cent less shore line than a square reservoir of equal area, and the surface of the water is less exposed to winds when the reservoir is partially filled. An oblong rectangular reservoir with one of its short sides toward the prevailing wind may have a smaller shore line exposed to wind, but it has a greater shore line, varying from 13 per cent up, depending upon the ratio of sides to ends, and in view of the fact that the seepage of water through the banks is approximately 20 per cent of the loss in the bottom of equivalent area it is desirable to reduce to a minimum the length of embankment. What has been said concerning shore line applies to the wave cutting of banks also. Round reservoirs in all sizes are more simple to construct. In orchards rectangular reservoirs conform better to the layout of plats, which are usually in squares or rectangles; but this does not offset the many advantages of the round ones.

The reservoir should be of sufficient size to hold the water pumped between irrigations. If the period between irrigations is ten days, and the pump delivers 60 gallons per minute on an average, the quantity pumped would be 864,000 gallons, or 115,500 cubic feet. The reservoir at Cheyenne lost about 10.5 per cent of its capacity in ten days, but this is not representative of earth reservoirs, which may lose 50 per cent in ten days. Assuming the loss to be 25 per cent, the capacity required would be 86,625 cubic feet, just a little less than 2 acre-feet. The reservoir should have some additional capacity to provide for the water pumped during a few days if irrigation is postponed for any reason.

Having decided upon the capacity of the reservoir, the next step is to decide upon the depth. In order that all the water in the reservoir may be available, the bottom of the reservoir must be above the land to be irrigated, and additional depth in the reservoir means additional lift for the pump and increased seepage losses per unit of bottom area, but, on the other hand, it decreases the surface area exposed to evaporation. No set rule for depth can be given, but considering all factors it is not deemed wise to make the depth of these small reservoirs more than 5 feet. Knowing the capacity desired and the depth, the area of the reservoir is found by dividing the number of cubic-feet capacity

by the number of feet in depth. If the reservoir is to be rectangular, the area in square feet divided by the length in feet will give the width. If it is to be circular, divide the area in square feet by 0.7854 and extract the square root of the product to find the diameter. These statements apply to reservoirs with vertical sides, such as masonry or concrete walls; but the banks are ordinarily made of earth and must be sloped, the usual slopes being 2.5 or 3 feet horizontal to 1 vertical, and the diameter found above will be the diameter at one-half the depth. To find the top diameter, multiply the depth by the number of feet of horizontal slope to one vertical, that is, by 2.5 or 3, as the case may be, and add this product to the diameter at mid depth and subtract it to secure the bottom diameter.

The following table gives the dimensions of circular reservoirs of different capacities; the quantities of earth in the embankments, if these have inside slopes of 3 to 1 and outside slopes of 1 to 1; the areas which can be irrigated, provided the reservoir full of water is used once in ten days throughout five months and the land receives water to a depth of 1 foot; the sizes of mills recommended, and the costs of reservoirs and mills. The lift assumed in chosing the mills is 14 feet.

Sizes of circular reservoirs and estimated cost for various areas of land to be irrigated.

Gross capacity of reservoir.	Depth of reservoir.	Diameter at bottom of embankment.	Diameter at top of embankment.	Bottom width of embankment.	Top width of embankment.	Amount of fill required.	Number and size of mills recommended.	Estimated cost of reservoir.	Estimated cost of plant erected and completed.[a]	Area irrigated.
Acre-feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Cu. yds.*				*Acres.*
0.07	4	21.30	45.30	19	3	212.00	1 8-foot..	$21.20	$81	1
.16	4	34.96	58.96	19	3	281.52	1 8-foot..	28.15	88	2
.24	4	45.62	69.62	19	3	336.25	1 10-foot.	33.62	113	3
.32	4	54.61	78.61	19	3	381.88	1 10-foot.	38.18	119	4
.40	4	62.27	86.27	19	3	422.46	1 12-foot.	42.24	202	5
.49	5	58.58	88.58	24	4	684.71	2 10-foot.	68.47	228	6
.56	5	63.64	93.64	24	4	725.80	2 12-foot.	72.58	392	7
.63	5	69.00	99.00	24	4	747.75	3 12-foot.	74.77	550	8
.72	5	74.37	104.37	24	4	813.51	3 12-foot.	81.35	561	9
.80	5	79.36	109.36	24	4	854.16	3 12-foot.	85.41	565	10

[a] Not including well.

CONSTRUCTION OF RESERVOIRS.

If possible a site should be chosen where the natural surface of the ground which will become the bottom of the reservoir is above the land to be irrigated, and if the highest land to be irrigated is some distance from the reservoir the bottom should be enough higher than the land to give a slope of at least 6 feet to the mile from the reservoir to the land.

All sod and vegetation should be removed from the site, as the decay of the roots will leave passage for seepage. In a circle midway between the outside and inside bank line plow a trench 2 feet wide

and 1 foot deep, removing this dirt to the outside of the bank; fill in this trench with clay, or with a clay and gravel mixture. After a part of the trench has been so filled add water, and thoroughly puddle so as to form a bond between the original walls of the trench and the material added; haul in additional clay material to this section of the trench until it projects above the original ground surface at least a foot and is yet a soft mass; then proceed to build the banks, puddling and tamping the new fill so as to thoroughly bind with the core of clay material. Proceed with the embankment until the first course to a depth of 6 inches has been completed around the entire inclosure, then add a second course of the same thickness around the entire wall, allowing the teams to walk upon the top of the banks a distance of at least 20 feet each time a scraper is dumped, for in this way each course is well tamped as the work progresses. It would be far better if each course could be thoroughly wet down so as to puddle it or better to tamp the embankment; and even better results would be obtained if the clay core could be carried up with the work to the top of the bank, though this is not an easy matter and is not imperative if the material used in constructing the banks is of a clayey nature. It is well to allow the banks to settle under several rains or snows before the reservoir is filled.

The inside slope of the bank should be very gradual, so as to avoid erosion and cutting. The width of the top of the bank should be not less than 3 feet for a reservoir 4 feet deep, and 4 feet for one 5 feet deep. The slope of the outside of the embankment may be steeper, 1 to 1 if planted to grass, so as to avoid washing or cutting from rains.

Haul into the bottom a lining of clay or clay mixture several inches in excess of the depth of soil removed, and after distributing it evenly pump into the reservoir sufficient water to form a thick muck or paste and thoroughly puddle by keeping cattle or sheep in the reservoir for at least a week, and better for thirty days. Indeed, the entire success of the reservoir is dependent upon such puddling, and there can be no reason why, by placing a temporary fence around the inclosure, the cattle or sheep can not be fed and watered while so penned up for thirty days. It will of course be necessary to allow water to run into the reservoir in small quantities during the operation of puddling, so as to maintain a soft puddle. After the work of puddling is completed the banks may be trimmed to line by shovel.

The inlet and outlet pipe should be put in place while the banks are being constructed, for in this manner a water-tight joint between the pipe and banks can be secured.

Many unique homemade valves or gates have been used, two of which are given in figures 10 and 11. The more permanent and durable the valve the less trouble will be experienced in its operation.

A pipe of about 20-gauge galvanized iron, 6 to 8 inches in diameter and provided with a single low-pressure water-gate valve will be the most reliable. The pipe will permit of a galvanized-iron collar being soldered on where it passes through the bank to prevent the water flowing around and along the pipe, which would tend to cut away the bank. The use of galvanized-iron pipe offers also a ready means of connecting to a distributing pipe outside the reservoir. The use of a gate or square flume may be desirable if the water from the

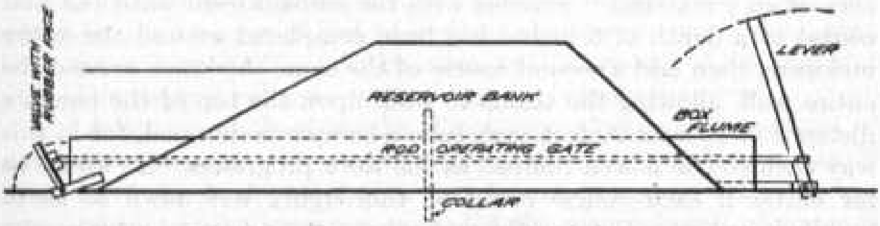

FIG. 10.—Wooden pipe outlet for small reservoir.

reservoir is to empty into an irrigating ditch, but in this case, as with the iron pipe, a projection should be nailed securely around the flume midway of the bank to prevent washing around the box, and in addition thereto there should be wing boards at the inlet and outlet faces to prevent cutting.

A very great economy in the distribution and conveyance of water to the land can be effected by the use of light, riveted, galvanized-iron pipe. These pipes are 6 inches in diameter of 20-gauge iron,

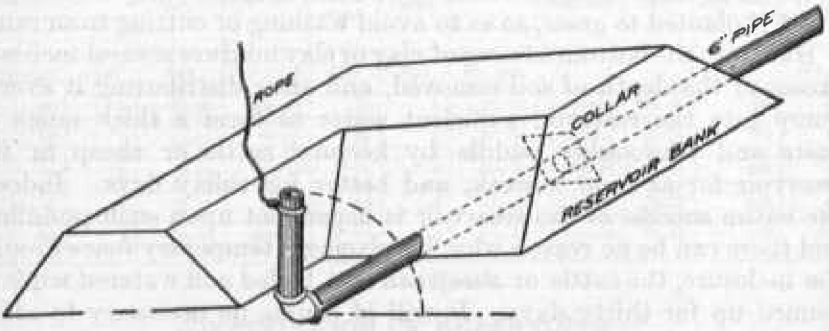

FIG. 11.—Pipe outlet for small reservoir.

riveted and soldered at transverse and longitudinal seams into sections 16 feet long. The ends are made tapering so as to enter easily when slipped together, but become tighter after entering 4 inches. Several elbows 90° and 45° are provided, thus allowing the pipe line to be run in any direction to the point of use. It was found by the use of these pipes at the Cheyenne station that an acre of land situated 500 feet from the reservoir could be irrigated from the reservoir to a depth of 0.25 foot in seven hours when the reservoir head was 2 feet,

and this without the loss of water from seepage and evaporation characteristic of an earth ditch. The cost of such piping is not over $27 per 100 feet, and its life with careful use should be indefinite.

The loss from evaporation in the reservoir can be reduced effectually by the planting of bush willows or some similar low-bush tree profusely around the top of the banks, thereby breaking the wind. The cutting of banks from wave motion can be eliminated entirely in an earthen reservoir by floating a boom of old railroad ties or other timbers around the inner banks facing the direction of the prevailing wind, or if desirable around the entire reservoir. The ties should be held together at the ends by cleats securely nailed and the entire boom should be anchored in a line 3 feet from the banks (fig. 12).

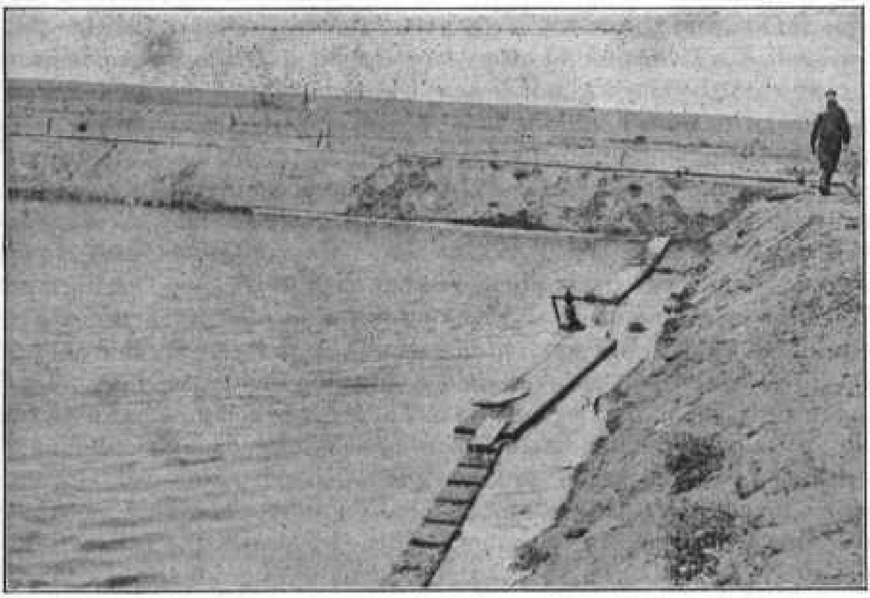

FIG. 12.—Boom to prevent erosion of reservoir banks by wave action.

In previous pages the treatment of reservoirs to reduce seepage or percolation losses was mentioned, and, while this is not essential, if a reservoir is constructed of clay and thoroughly puddled, it is often the case that desirable material is not at hand and it becomes necessary to resort to a method of lining as a substitute for puddling. A bulletin upon this subject by B. A. Etcheverry[a] gives much valuable information upon the subject, so that a discussion of the relative merits of the various linings will not be entered into here, except that a brief account will be given of an experiment at the Cheyenne (Wyo.) station. Here the reservoir was divided into three compartments

[a] California Sta. Bul. 188.

for the purpose of trying various methods of lining in connection with windmill irrigation. The material of which this reservoir is constructed is a porous sandy soil which seems to resist puddling, as shown by the fact that the average total loss in the large compartment after thoroughly puddling with manure cast over the bottom was 0.35 foot per 24 hours after three months constant use. Nine sacks of cement were cast over the surface of the water with a view to sealing the voids or pores of the soil, but the gain was insignificant and further attempt in this compartment was abandoned, and a treatment of tar was applied to one of the smaller compartments, with a capacity of approximately 0.29 acre-foot. The bottom and banks of this compartment were raked to a mulch 2 inches deep and tar in a boiling state was sprinkled from pails having holes punched in the bottom. The total amount of tar applied was 504 gallons, or 0.121 gallon per square foot, and the cost was about 1.1 cents per square foot for the tar applied. It was found after the reservoir so treated was put into service that the loss was not lessened in the slightest degree and was more than twice that of the large compartment after puddling. A second method of lining with tar was employed in the other small compartment. The banks and bottom were packed and the reservoir was filled and the water allowed to seep away thereby securing a well-packed surface. The reservoir was then allowed to dry out thoroughly and two coats of tar were applied in the same manner as for the other compartment. The quantity applied at the first coating was about 1 gallon per square foot, while the quantity applied at the second coating was approximately 0.06 gallon per square foot. The soil, being packed, did not take up as much tar as the mulched surface did. The reservoir was put into service soon after being treated and the loss was found to be 0.93 foot per 24 hours. However, during constant use for thirty days the loss rapidly decreased until it averaged 0.072 foot per 24 hours. This decrease in the rate of loss was probably due to the fact that the voids were gradually closed by pressure of the water on top and as the tarred particles retained their plastic and adhesive coating they united this coating and the voids became sealed. The fact that when the reservoir was allowed to dry out and then fill again the loss at the start was large, but soon became less, would tend to disprove the above statement, but observation shows that when the soil becomes dry and heated a heaving or movement due to expansion and contraction tends to break up the film which united the sand particles, thereby again opening the voids to percolation. This would be avoided no doubt if the surface could be rolled under heavy pressure, but it is not practicable to so tamp a reservoir. A clay puddle if allowed to dry out cracks so badly that it must be puddled again after each drying.

At the station at Eads, Colo., experiments were made with a reservoir of similar proportions, one compartment of which was treated with oil residuum having an asphalt basis, but it was found that the advantage of such a lining was not marked, and after repeated trials the reservoir was finally puddled by stock, and the oil-treated surface was thereby thoroughly mixed with the soil, and a comparatively tight reservoir was secured.

In view of the fact that experiments with various crops were in progress at the Cheyenne station and an assured supply of water was imperative, it was decided to line the large compartment with concrete, and a 3-inch lining was accordingly applied. The rough body was 2 parts coarse sand, 3 parts gravel, and 1 part cement, while a one-fourth-inch dress coat of 1 part sand to 1½ parts cement was placed upon the rough body and left a sand finish as produced by float. Quarter-inch iron rods were used for reenforcement at all corners and angles. The total cost of the lining of this reservoir, having a capacity of 0.8 acre-foot was close to $1,000, and while so great an expense would in many instances be prohibitive to the farmer, the very great saving in water would pay a large rate of interest upon the investment, and it is to be favored in all instances where the expense can be borne. The expense for concrete lining lies very largely in the labor, and with careful attention to the work much, if not all, of it could be done with ordinary unskilled labor, and the expense for lining would thereby be reduced greatly, because it could be done at a time when it would not conflict with the work on the farm. Where a concrete lining is to be applied it is well to drain the reservoir site thoroughly by a system of tile drains, so as to prevent freezing and upheaval of the ground beneath. Also concrete should not be applied to the newly constructed banks, but they should be allowed to settle and pack with water in the reservoir for several months.

MAINTENANCE OF MILLS.

It is unfortunate that the windmill has attained a reputation of not needing attention except at times of breakdown, and conditions are aggravated by the attempts of makers to include automatic oiling devices, which are claimed to be so reliable as to need no attention during an irrigation season. While such devices are commendable in machines operating in places where daily observation is possible, they are out of place in a windmill, which by virtue of its nature must be placed high above the ground, where a special effort must be made if inspection is had, and where it is exposed to the dust and the elements and where the loosening of a bolt may ultimately cause the ruin of the entire engine. Probably from no machine is so much expected for so little attention as from a windmill, and probably no machine will give

so much in return for so small an initial investment and so great an amount of energy from nature's store without cost to man. It is a mistake for manufacturers to advertise the simplicity of their particular make of mill and the small amount of attention needed, for in doing so they encourage a still greater neglect and indifference on the part of owners.

It is to be hoped that as the demand for irrigation plants using wind power becomes recognized, manufacturers will strive to build mills of heavy construction scientifically and mechanically built with all working parts machined properly and provided with liberal and positive oiling facilities, and will make vigorous efforts to impress upon the users the similarity between the windmill and any other type of engine with respect to the necessity of thorough oiling and systematic inspection. It is further to be hoped that the purchaser will not be guided in his choice by the cheapness of the product, but by excellence, and it is not amiss to say that very often the cheapest article, whether a mill or a wagon, is in the long run the most expensive.

CROPS UNDER WINDMILL IRRIGATION.

The particular locality of the farm must decide very largely the character of the crops to be raised. If the area under windmill irrigation be increased, it will not be necessary to increase the vegetable garden unless it is desired to engage in truck gardening for a market, but by increasing the grain and forage crop area a larger number of animals can be carried over, or some of the products may be sold. The average value of the crops raised on 2 acres is given, and the returns show conclusively the possibilities of such practice in the cultivation of semiarid lands.

Estimate of crops grown on an ideal windmill irrigation tract, with their values.

Alfalfa, 1 acre, 3 tons, at $10	$30
Potatoes, three-sixteenths acre, 25 sacks, at $1	25
Corn, one-fourth acre, 10 bushels and fodder	10
Pumpkins and melons, one-fourth acre	20
Garden vegetables, one-sixteenth acre	30
Fruit and berries, one-fourth acre	50
Total	165

WINDMILLS IN USE.

What has preceded is in the nature of suggestions made with a view to aiding those who contemplate the installation of a windmill plant, so that installations of a more permanent and reliable character may result, but no greater education can be gained in the conduct of any enterprise than by observation of what has been or is being done by

others on similar lines. Data gathered by inspection and observation of many plants now in operation throughout the Western States follow:

WINDMILLS IN WESTERN KANSAS AND NEBRASKA.

An effort has been made to present in the following table the facts of greatest interest, including (1) how much land is irrigated, (2) what is planted on this land, (3) how many trees, (4) what size mills are used, and (5) how large is the reservoir.

For easy reference, each plant is given a number, so that those interested in the details of a plant may follow it through the table without reference to the owner.

Condensed data of windmill irrigation.

GARDEN CITY, KANS.

Number of plant.	Area.	Crops.[a]	Number of trees.	Size of mill.	Cost of plant.	Size of reservoir.	Cost of reservoir.	Annual maintenance.	Value of crops.
	Acres.			*Feet.*		*Feet.*			
1	4.0	G and C	100	10; 12	$200	100 by 30 by 2.	$20	$4.00	$300
2	20.0	G; SB; A	400	25; 10; 10	1,000	100 by 200 by 4.	150	2.50	1,500
3	6.0	G; F; SB	700	12	200	75 by 100 by 5.	20	.50	1,200
4	4.0	A and SB	....	12	200	75 by 100 by 5	20	.50	250
5	25.0	A	800	[b] 3-12	360	90 by 185 by 3.5	100	30.00	1,600
6	8.0	A	....	12	120	150 by 60 by 3.	50	10.00	350
7	8.0	G; SP; C.	....	12	150	100 by 3, round	45	3.65	800
8	2.5	G	100	8	55	30 by 100 by 3.	10	4.00	125
9	4.0	G; F; Fl.	300	8; 10	85	30 by 35 by 3.5	15	2.00	200
10	3.0	G	100	10	102	20 by 70 by 2.	15	1.50	500
11	2.0	G; F	40	10	75	30 by 50 by 2.	12	....	150
12	8.0	G; F	800	8; 12	185	85 by 110 by 3.	40	11.00	550
13	5.0	B; F; G	125	10	100	50 by 100 by 2.5	20	2.00	500
14	1.5	B; F; G	200	8	92	24 by 24 by 2.	10	.75	400
15	2.5	G	100	8; 10	70	30 by 30 by 3.	10	....	300
16	2.0	G and F	800	14	175	75 by 75 by 3.5	25	5.00	....
17	7.0	G and SB	150	2-12	230	125 by 125 by 3.	40	30.00	200
18	2.0	G	146	8	70	40 by 40 by 2.5	15	.50	150
19	1.0	G	200	8	12	35 by 35 by 2.	10	3.00	200
20	5.0	B; F; G	800	2-8	150	50 by 50 by 2.5	50	1.50	300
21	4.0	G and F	3,000	12	103	75 by 75 by 2.5	15	.50	500
22	4.0	SP	....	10	93	30 by 70 by 3.	15	.50	250
23	.25	C	30	8	62	50 by 50 by 3.	25	.50	100
24	3.0	G and F	300	10	91	25 by 25 by 2.	10	1.50	500
25	10.0	G; A; F	1,000	10; 12	230	100 by 110 by 3.	30	1.50	750
26	3.0	B; F; G	260	8; 8	90	30 by 50 by 3.	13	1.35	500
27	4.0	G and F	375	12	128	50 by 30 by 3.	12	15.00	500
28	12.0	G and F	500	2-12	225	100 by 500 by 3	50	....	500
29	10.0	G and F	150	2-12	193	75 by 100 by 2.5	15	....	1,500
30	5.0	B; F; G	100	12	72	60 by 60 by 4.	20	5.00	200
31	2.5	B; F; G	100	2-8	164	40 by 50 by 2.	10	.75	200
32	2.5	B; F; G	75	8	60	60 by 60 by 3.	20	5.00	200
33	4.0	G	....	12	85	2.5 by 50 diam.	40	7.00	200
34	4.0	G	300	12; 8; 8	250	100 by 100 by 3.	50	12.00	300
35	2.0	G	800	8	75	20 by 25 by 2.	10	None	100
36	10.0	T	2,000	2-12	200	250 by 100 by 3.	75	....	700
37	2.5	G	150	10	75	20 by 111 by 2.5	10	5.00	175

INGLES, KANS.

Number of plant.	Area.	Crops.	Number of trees.	Size of mill.	Cost of plant.	Size of reservoir.	Cost of reservoir.	Annual maintenance.	Value of crops.
38	7.0	G and A	230	16; 10	$225	100 by 150 by 2.	$50	$10.00	$175

[a] The following abbreviations are used: A, alfalfa; B, berries; C, cantaloups; F, fruit; Fl., flowers; G, garden; SB, sugar beets; SP, sweet potatoes; St, strawberries; T, trees.

[b] This indicates three 12-foot mills. Other similar figures indicate number of mills of the size given.

Condensed data of windmill irrigation—Continued.

Number of plant.	Area.	Crops.[a]	Number of trees.	Size of mill.	Cost of plant.	Size of reservoir.	Cost of reservoir.	Annual maintenance.	Value of crops.
					CIMARRON, KANS.				
	Acres.			*Feet.*		*Feet.*			
39	3.0	F; A; G	1,000	8; 10	$200	75 by 75 by 2	$20	$10.00	$200
40	2.0	G	150	10	105	20 by 33 by 3	25	3.00	90
41	1.0	G	75	10	92	30 by 50 by 3	6	4.00	100
					DODGE CITY, KANS.				
42	2.0	G	300	8	$92	30 by 30 by 3.5		$0.50	$200
43	.5	G	150	6	46	2 by 25 diam			75
44	5.5	G	170	10; 12	215	110 by 200 by 2	$50	20.00	1,000
45	3.0	G and F	900	10; 8	200	110 by 200 by 2.	20		200
46	1.0	B; F; G	90	6	65	25 by 45 by 3	15	50.00	200
47	4.0	F; A; G	900	12	400	9 by 16 diam	100	1.35	200
48	.5	T (orchard)	1,804	10	60	42 by 67 by 2			
49	2.0	B; F; G	150	6; 8	125	90 by 100 by 2.	20	.50	500
					KINSLEY, KANS.				
50	4.0	G and F	500	12	$400	5 by 50 diam	$25		
51	.5	SP and G		8	58	30 by 55 by 5	15	$1.50	$75
52	.25	G and T	2,000	8	60	Standpipe		.50	600
53	2.0	G and F	100	12	171	64 by 190 by 2.	60	2.00	400
54	2.0	G		12	122	38 by 115 by 2.	30	2.00	400
55	5.0	B and G	100	12	172	40 by 60 by 4	100	25.00	1,000
					GREAT BEND, KANS.				
56	.5	B and G	200	10	$125			$0.75	$100
57	1.0	B and G		6	61	5 by 5 diam	$24	.50	200
58	5.0	B and A	50	12	75	110 by 150 by 2.	500	5.00	800
					HUTCHINSON, KANS.				
59	2.5	B and G		8		8.5 by 7.5 diam			
60	4.0	St		12	$270			$0.50	$800
					HUTCHINSON, NEBR.				
61	1.0	G	10	8	$83			$0.50	$100
62	1.0	G	300	8	55	6 by 5 diam	$175	3.00	75
63	4.5	G and A	60	8	75				125
64	6.0	G and F	300	10	135	66 by 65 by 3	100	.50	600
65	1.3	G	25	6	90	6 by 5 diam	100	.50	50
66	14.0	A and G		12	125			1.00	1,000
67	10.0	G	850	16	250	100 by 200 by 2.	100	3.00	600
68	10.0	A	25	2		100 by 200 by 5.			
69	10.0	G	225	[b]3-8; 12; 14		200 by 100 by 3.	100		600

[a] The following abbreviations are used: A, alfalfa; B, berries; C, cantaloups; F. fruit; Fl, flowers; G, garden; SB. sugar beets; SP, sweet potatoes; St, strawberries; T, trees.
[b] The three 8-foot mills not now in use.

While in some instances the gross returns for crops from these small areas are not so high as to present an attractive commercial aspect, it should be borne in mind that the main purpose of this bulletin is not to show the advantage of truck gardening or horticulture as a commercial enterprise, though the possibilities in this field are very great, but to encourage the cultivation of small areas of irrigated land in connection with the farming without irrigation of

large areas of land which must necessarily fail to produce crops during seasons of scanty rainfall. However valuable may be the results obtained by cultivation after rainfall or summer fallow of land whereby a part of two years' moisture may be conserved to be used in one year's cropping, it must be conceded that a lack of moisture in natural precipitation can not be compensated for by any method of tillage of soil, and loss must necessarily ensue during the years of drought. During past years, many an ambitious farmer has taken up land under arid conditions and after several years of deprivation and toil has been compelled to abandon his homestead, not infrequently being compelled to dispose of his household effects in order to acquire means to defray the expense of travel. Not many years have elapsed since entire towns, built during years of plentiful rainfall, have been abandoned because of several years of meager precipitation, only to be resurrected during a recurrence of a succession of wet years. One instance is recorded where in five years more wheat has been sown on a section of land under dry-farming practice than has been harvested. In this instance, the owner had prospered in cattle raising; but, being aroused to enthusiasm by the great claims for new systems of dry farming, he was induced to dispose of his cattle to realize greater returns from his land, with the result stated. How different would be the conditions if 5 or 10 acres of each homestead were planted to the crops necessary to domestic need and to the feeding of the few head of stock required in the conduct of farm operations, and this small area were irrigated by windmills. In times of limited precipitation, when cropping of the large area is not feasible, abandonment of the entire homestead will not be necessary.

WINDMILLS IN EASTERN COLORADO.

Eastern Colorado represents a region which was principally a dry-farmed district formerly, but which, during years of scanty precipitation, was practically abandoned because of the inability of the farmers to secure a livelihood from the land without irrigation.

The use of windmills in this section of the West was not primarily for irrigation, but for stock water, though it was soon found that, during the time when they were not needed for such purposes, they could be employed in the irrigation of a few trees or perhaps a small garden plat; but this secondary use of the windmill was discontinued as the stock-water demand increased, and this condition continued until the price of cattle became so low as to discourage the small stock raiser, when he turned again to the tillage of the soil. It was then that the great possibilities of irrigation from windmills in that district became known and exploited. A marked contrast exists between the farmers dependent upon the raising of stock alone or the cultivation of dry-farm areas without irrigation, and those

who have converted a small part of their land into windmill-irrigated plats in this part of Colorado. It is a noteworthy fact that the use of the windmill is confined to districts where the success of one plant has been a stimulus to others. Where the initial plant has been a failure, owing possibly to improper loading of the mill or to excessive head, those who might otherwise have been successful have not been inclined to investigate the cause of failure, and so continue in indifferent success, always with the possibility of a complete failure during years of insufficient rainfall. It is of interest also to note that those plants which are successful are owned by men who were compelled by circumstances to count the cost of every expenditure and to do those things themselves which others might have hired done. These men, too, have practiced the greatest economy in the use and application of water to the land and have increased the irrigated area from a few rods to perhaps several acres, or as fast as their experience taught them it could be increased with the original supply, or by increasing the capacity within their means.

The average depth of water applied to the land in this part of the West is about 6 inches, which, in addition to the average rainfall, makes 16 inches during the growing season; and while some years the trees require no water other than the natural rainfall, the succulent vegetables receive water whenever it is needed. With proper soil cultivation a considerable amount of moisture may be conserved from the winter snows, though this depends on the character of the soil, its depth, character of subsoil, and the extent to which cultivation is carried on.

The investigation of windmill-irrigated plats in eastern Colorado included dry farms of 20 to 200 acres. The total record includes 2,320 acres dry-farmed, upon which the average gross annual return per acre was $6.50. The average cost of production was between $2 and $3 per year. The average cost of 8, 10, 12, 14, and 16 foot mills, together with the average area irrigated, is given in the table following. It will be noted that the areas irrigated are far smaller than recommended and smaller than are being irrigated in parts of Kansas and Nebraska. The primary reason for this is that the lift is much greater than in Kansas and Nebraska.

Average cost of mills of different sizes, and areas served in Colorado.

Number of mills.	Size of mills.	Average cost.	Average area.
	Feet.		*Acres.*
18	8	$102	0.7
12	10	198	1.8
9	12	195	2.4
8	14	265	3.8
2	16	188	3.6

The following is a tabulated statement of plants investigated. It was difficult to ascertain exact cost, owing to the fact that much of the work of installation and construction was done by the owners themselves, and no record of the time employed was kept. The original cost of the plant includes only the cash outlay in most instances.

Data relating to windmill irrigation in eastern Colorado.

Number of plant.	Area irrigated.	Crops.[a]	Value of crops.	Area dry-farmed.	Size of mill.	Lift.	Size of cylinder.	Reservoir. Size.	Reservoir. Capacity.	Cost of plant.	Cost of maintenance.	Value of plant.
	Acres.			*Acres.*	*Feet.*	*Feet.*	*Inches.*	*Feet.*	*Cu. ft.*			
1	0.25	G	$50	150	10	115	2.0	75 by 16 by 9	10,800	$1,200	$5.00	$1,500
2	1.00	G and T	100	25	10	45	3.0	.....	248	175	2.50	500
3	⅓	G	100	4	10	14	3.0	.....	3,000	225	5.00	500
4	2.00	G	100	.....	10	11	4.0	.....	200,000	250	5.00	1,000
5	1.50	G, F, T	200	.....	10	84	4.0	40 by 60 by 6	14,400	300	6.00	500
6	.50	G	100	20	8	33	3.0	40 by 50 by 4	8,000	150	10.00	300
7	.75	G and T	150	70	10	71	3.0	28 by 14 by 2	784	175	5.00	1,000
8	1.00	G and F	100	40	8	64	2.5	22 by 12 by 3	792	75	10.00	500
9	3.00	G, SB, T	248	.....	10	17	4.0	150 by 60 by 2	18,000	175	8.00	500
10	2.00	G and F	125	105	12	65	4.0	150 by 50 by 3.5	15,750	200	9.00	500
11	4.00	G and F	200	225	16	62	5.0	100 diameter	31,416	175	20.00	1,000
12	4.00	G and F	200	225	14	.....	.....		.....	150	18.00	
13	5.00	G and F			14	74	5.0	.....	84,000	400	20.00	1,000
14			200	100	12	62	4.0			230	25.00	
15	8.00	No returns			15	54	3.5	130 by 130 by 4	171,600	300	18.00	400
16					8	15	5.0					
17	16.00	A, F, and G	540	200	8	20	4.0	60 by 60 by 6	21,600	400	4.00	2,500
18					8	20	4.0					
19					8	15	5.0	40 by 60 by 2	4,800			
20	1.50	G and F	150	130	9	11	4.0	60 diameter	8,160	150	3.00	500
21					8	15	4.0					
22	2.00	G and F	200	150	12	115	2.5	30 diameter	2,600	400	15.00	1,000
23					10	115	2.5	.....	1,760			
24	1.00	G and F	200	None.	8	5	2.5	(b)	.....	80	10.00	1,000
25	1.00	G and F	75	130	8	20	4.0	(b)	.....	100	5.00	1,000
26	1.00	G and F	200	70	8	23	4.0	.....	4,542	100	5.00	1,000
27					8	18	2.5	(b)	.....	100	7.00	
28	2.00	V and F	300	30	8	19	4.0	.....	19,250	150	8.00	1,500
29					8	18	2.5	(b)	.....	50	5.00	
30	2.00	G and F	200	60	8	14	4.0	.....	8,100	200	8.00	1,000
31	2.00	G and F	200	70	8	14	3.0	.....	8,000	100	6.00	1,000
32					8	14	4.0	.....	21,000	100	6.00	
33	.25	G and F	100	75	8	65	2.0	.....	216	100	10.00	300
34	5.00	G and F	300	40	16	18	6.0	16 by 10 by 2	512	200	15.00	1,000
35	1.00	G and F	100	130	12	.....	.....	25 by 00 by 3	4,500	150	10.00	500
36	4.00	G, F, T	100	100	14	81	.....	53 by 63 by 5.5	18,000	365	15.00	5,000
37					14	65	4.0	120 by 60 by 4	28,800	225	10.00	
38	13.50	St., G, F	560	70	14	66	4.0	90 by 90 by 4	32,400	225	10.00	2,000
39					14	72	4.0	60 by 60 by 3.5	12,600	225	10.00	
40	.50	G and F	150	160	12	120	2.5	20 by 60 by 2.5	3,000	275	15.00	.....
41	1.50	G and F	150	10	10	125	2.5	.....	378	275	5.00	1,000
42	2.00	G and P	150	100	14	220	3.0	.....	1,353	305	15.00	1,000
43	.50	G and T	100	75	10	12	3.0	.....	.....	175	6.00	200
44					8	20	2.5	.....	.....		4.00	
45	12.00	G and P	575	None.	14	14	5 and 4	80 by 110 by 4	35,200	400	15.00	2,000
46					12	14	4.0					
47	8.50	G and SB	480	None.	12	18	5.0	50 by 110 by 2	11,000	190	0.00	1,000
48					10	15	4.0	50 by 50 by 2.5	3,750	160	4.00	
49	1.00	G and F	100	30	12	14	3.5	(b)	.....	100	.....	300
50					10	40	4.0	(b)	.....	135	.....	
51	10.00	G and P	500	None.	10	40	4.0	16 by 32 by 2.5	1,280	150	.....	1,000
52					12	45	6.0	75 by 75 by 4	22,500	215	.....	

[a] A, alfalfa; F, fruit; G, garden; SB, sugar beets; St, strawberries; T, trees.
[b] No reservoir.

WINDMILLS NEAR STOCKTON, CAL.

The windmill universally used for irrigation purposes in the vicinity of Stockton, Cal., is a wooden wheel 22 feet in diameter, bolted to a

2-inch crank shaft, which has a direct stroke of 12 inches. The bearings of the shaft are made of hard maple and mounted on a turntable on the top of a 40-foot wooden tower. The wheel has to be turned into the wind by means of a pole fastened to the turntable, operated by two ropes, as shown in figure 13. The mill is connected by a driving pole to a walking beam about 12 feet long, at either end of which is fastened the driving rod of an 8-inch cylinder pump, as shown in figure 14. The connection of the main driving pole to the walking beam is a ball and socket joint and is shown clearly in figure 14. This tandem mill will raise about 300,000 gallons of water per day under favorable conditions. The illustration gives the dimensions used ordinarily. The pumps are of the cylinder-suction type, with two valves, the prevailing sizes being 8 and 9 inches. There are two types used. The plunger with its metal valve is the same in both kinds, but the lower valves differ. One is the regular hinged valve cut out of rubber packing with a weight fastened to the top of the hinged portion to keep it closed on the downstroke of the plunger (fig. 15). The other type has a metal lower valve similar to the valve in the plunger.

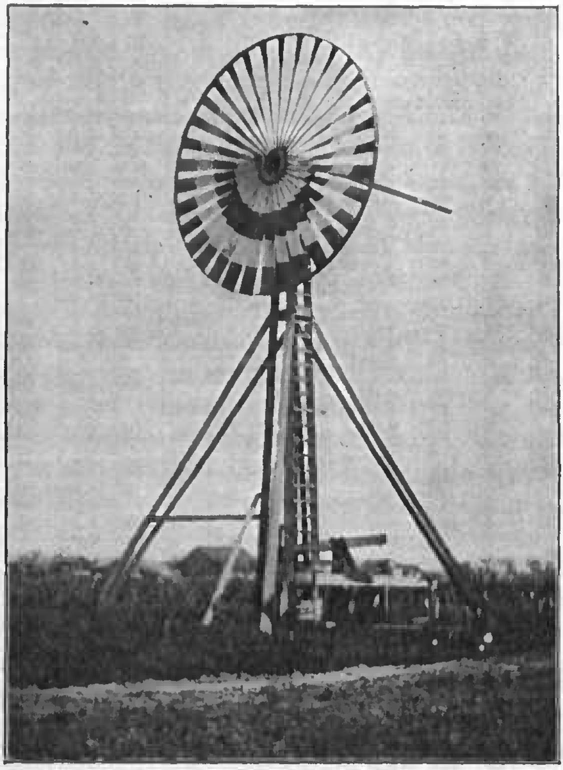

FIG. 13.—Wheel turned into the wind and held there by means of ropes.

Most of the wells in this section are bored in order to get below the surface water and avoid the alkali, for the water table lies about 15 feet below the ground line. The wells are cased at the time they are bored, and often reach to a depth of over 100 feet. Then the water rises to within 10 or 15 feet of the surface of the ground. The well is bored down to a stratum of sand and then the sand is pumped out, forming an underground reservoir.

The wooden mill has outclassed the steel mill in this vicinity, both in maintenance and length of satisfactory usefulness. Some of the old wooden mills in Stockton have been running for thirty years.

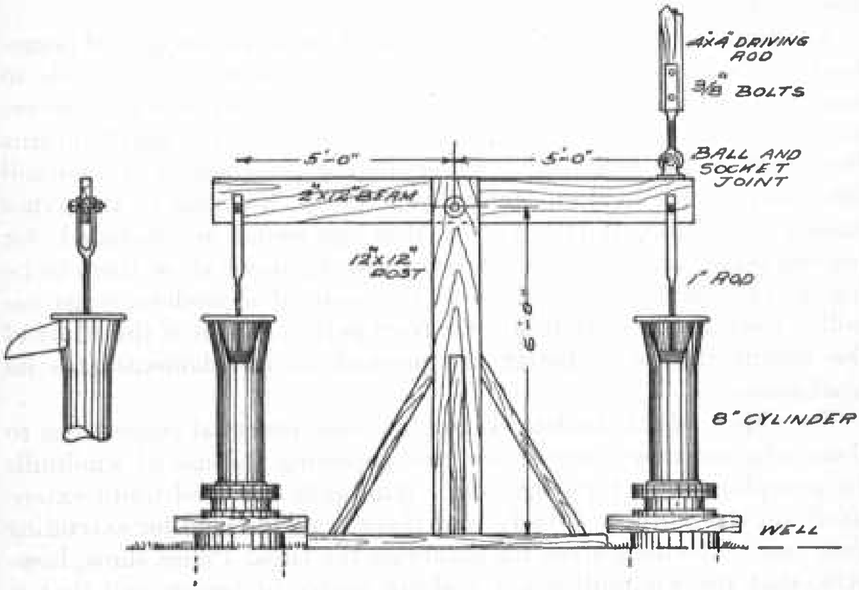

FIG. 14.—Manner of connecting driving rod of windmill to pumps used near Stockton, Cal.

It would be hard to say the same for the steel mills. Windmills are so placed as to irrigate the land most efficiently and are often such a distance from the house that it is inconvenient to oil them frequently or give them the proper care. For this reason the wooden mills have the advantage. The steel mills have metal bearings, which must be oiled very often during the season when most in use or they will heat and the friction will soon cut them out. The wooden mills have hard maple bearings which need a thorough oiling once a week until they are saturated, then once a month is sufficient. In case the wooden bearings do run dry no harm will result, while the bearings of the steel mills would be ruined, and the parts are not replaced conveniently.

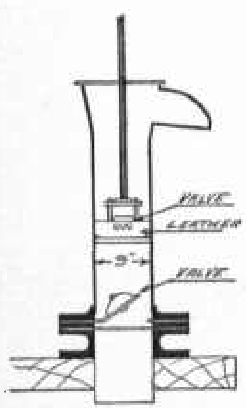

FIG. 15.—Type of pump used near Stockton, Cal.

Throughout this section the farmers having large areas to irrigate are using electric motors and gasoline engines with the centrifugal pumps, as they can be depended upon always, while the wind is uncertain as a motive power. No provision was made for storage of water in this section, as it seemed so plentiful. Undoubtedly if large

reservoirs were added to the windmill plants in this district the use of motors and gasoline engines would not be required, for there are few places where water may be secured in so large quantities at such shallow depths.

No attention has been given in this bulletin to the subject of home-made mills for irrigation, for the reason that while it is possible to construct a mill of some type where one has the tools and time necessary, as a rule the result is not satisfactory and the small returns from such a mill will tend to discredit the possibilities of windmill irrigation with a modern factory-built mill. No mills of the types known as Jumbo, Battle Ax, or Merry-go-round are included, for reasons stated above. The results of investigations show them to be low in efficiency and unsuited to the ends of a modern irrigation mill. Even the modern mill is far from perfect, but it is the effort of the manufacturers to better the product as use demonstrates its weaknesses.

The object of this bulletin is to give some practical suggestions to those who are now using or are contemplating the use of windmills for pumping water for irrigation. Windmills are used quite extensively for this purpose already, and there is a wide field for extending their use. The data given for plants on the Great Plains show, however, that the windmill is not a cheap source of power, and that it will not, as is so often claimed, run without attention. A windmill should be looked after as carefully as any other piece of machinery, and if this is done it will provide power for the irrigation of considerable areas at an expense which will be justified by the crops grown.

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